Selected decays of heavy mesons in covariant confined quark model: Semileptonic and Nonleptonic Decays of B_c Meson

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New high-energy and high-luminosity experiments nowadays allow for measurement of rare flavor-changing decays of heavy mesons. These are being of a special interest: new, hypothetical particles could contribute to the loops of corresponding Feynman diagrams, modify the Standard Model (SM) predictions and so manifest existence of new physics. One source of uncertainty in theoretical estimation of the SM values are hadronic effects. Covariant confined quark model (CQM) is a well-suited framework to estimate these and represents a desired alternative for cross-checking existing evaluations of other authors. The CQM is applied to B_c semileptonic and nonleptonic decays.

Covariant confined quark model (mesons)

- Non-local, Lagrangian based with full Lorentz invariance
- Limited number of free parameters (one per hadron + 5 global)
- Suited for various multi-quark states (mesons, baryons, tetraquarks)
- Quark-hadron interaction vertex (no gluons)

$$\mathcal{L}_{\rm int} = g_M \cdot M(x) \cdot J_M(x),$$

$$J_M(x) = \int dx_1 \int dx_2\, F_M(x, x_1, x_2) \cdot \bar{q}^a_{f_1}(x_1)\, \Gamma_M\, q^a_{f_2}(x_2),$$

$$F_M(x, x_1, x_2) = \delta\left(x - \omega_1 x_1 - \omega_2 x_2\right) \Phi_M\left[(x_1 - x_2)^2\right],$$

$$\omega_i = \frac{m_i}{m_1 + m_2}.$$

Compositeness condition

- Lagrangian: hadrons *and* quarks treated as elementary. Appropriate description of composite particle addressed already in 60ties [1,2].
- Compositeness condition: state properly described as bound if it does not contain the "bare" state, i. e. its overlap with it is zero → requirement on the renormalization constant :

$$Z_M^{\frac{1}{2}} = 0.$$

- Implementation into CQM makes appear derivative of the meson mass operator and removes couplings as free parameters

$$1 - \frac{3 g_M^2}{4\pi^2} \mathit{\Pi}'_M\left(m_M^2\right) = 0.$$

Infrared confinement

- Provide stability for (too) heavy mesons, prevent decay to constituent quarks.
- Related to integration over Schwinger parameters, the latter being used in the quark propagator representation

$$\widetilde{S}_q(k) = \left(m + \hat{k}\right) \int_0^\infty d\alpha\, e^{\left[-\alpha\left(m^2 - k^2\right)\right]}$$

- Integration region transformed: multidimensional simplex + singe improper integral
- Single global cutoff parameter λ introduced

$$\Pi = \int\limits_0^{\infty \to 1/\lambda^2} dt\, t^{n-1} \int\limits_0^1 d^n\alpha\, \delta\Big(1 - \sum_{i=1}^n \alpha_i\Big) F(t\alpha_1, \ldots, t\alpha_n).$$

Computations

- Numerical integration over Schwinger parameters used in computation of transition form factors (given by the CQM)
- Helicity formalism used for the model-independent amplitudes evaluation.

Results

- Branching rations are given as percentages

Mode	This work	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
$B_c^- \to \eta_c \ell\nu$	0.98	0.81	0.98	0.75	0.97	0.59	0.15	0.40	0.76	0.51	0.44
$B_c^- \to \eta_c \tau\nu$	0.25	0.22	0.27	0.23		0.20					0.14
$B_c^- \to J/\psi \ell\nu$	1.74	2.07	2.30	1.9	2.35	1.20	1.47	1.21	2.01	1.44	1.01
$B_c^- \to J/\psi \tau\nu$	0.42	0.49	0.59	0.48		0.34					0.29
$B_c^- \to \overline{D}^- \ell\nu$	0.0027	0.0035	0.018		0.004	0.006		0.0003	0.001	0.003	0.0032
$B_c^- \to \overline{D}^- \tau\nu$	0.0017	0.0021	0.0094	0.002							0.0022
$B_c^- \to \overline{D}^{*-} \ell\nu$	0.0050	0.0038	0.034		0.018	0.018		0.008	0.008	0.013	0.011
$B_c^- \to \overline{D}^{*-} \tau\nu$	0.0028	0.0022	0.019	0.008							0.006
$B_c^- \to \overline{D}_s^- \ell\nu$	0.0041										
$B_c^- \to \overline{D}_s^- \tau\nu$	0.0024										
$B_c^- \to \overline{D}_s^{*-} \ell\nu$	0.0069										
$B_c^- \to \overline{D}_s^{*-} \tau\nu$	0.0036										

Mode	This work	[3]	[5]	[6]	[7]	[8]	[10]	[13]
$B_c^- \to \eta_c D_s^-$	0.49	0.44	0.28	0.054	0.35	0.50	0.26	1.23
$B_c^- \to \eta_c D_s^{*-}$	0.79	0.37	0.27	0.044	0.36	0.057	0.24	1.65
$B_c^- \to J/\psi D_s^-$	0.515	0.34	0.17	0.041	0.12	0.35	0.15	0.81
$B_c^- \to J/\psi D_s^{*-}$	0.78	0.97	0.67		0.62	0.75	0.55	2.05
$B_c^- \to \eta_c D^-$	0.018	0.019	0.015	0.0012	0.010	0.005	0.014	0.044
$B_c^- \to \eta_c D^{*-}$	0.035	0.019	0.010	0.0010	0.0055	0.003	0.013	0.058
$B_c^- \to J/\psi D^-$	0.018	0.015	0.009	0.0009	0.0044	0.013	0.009	0.028
$B_c^- \to J/\psi D^{*-}$	0.032	0.045	0.028		0.010	0.023	0.028	0.067

Decay rate	This work	[3]	[12]	[14]
$R_{\eta_c} = \frac{B_c^- \to \eta_c \ell\nu}{B_c^- \to \eta_c \tau\nu}$	3.92	3.68	3.2	1.6
$R_{J/\psi} = \frac{B_c^- \to J/\psi \ell\nu}{B_c^- \to J/\psi \tau\nu}$	4.14	4.22	3.4	3.4
$R_{D^-} = \frac{B_c^- \to D^- \ell\nu}{B_c^- \to D^- \tau\nu}$	1.58	1.67	1.42	
$R_{D^{*-}} = \frac{B_c^- \to D^{*-} \ell\nu}{B_c^- \to D^{*-} \tau\nu}$	1.79	1.72	1.66	
$R_{D_s^-} = \frac{B_c^- \to D_s^- \ell\nu}{B_c^- \to D_s^- \tau\nu}$	1.71			
$R_{D_s^{*-}} = \frac{B_c^- \to D_s^{*-} \ell\nu}{B_c^- \to D_s^{*-} \tau\nu}$	1.92			

	$R_{D_s^{*+}/D_s^+}$
This work	1.51 ± 0.43
$ATLAS$[15]	$2.8^{+1.2}_{-0.8} + \pm 0.3$
$LHCB$[16]	$2.37 \pm 0.56 + \pm 0.10$
$QCDSR$[17]	3.9
Potential model[8]	1.7
$LFQM$[18]	3.01 ± 1.23
$PQCD$[19]	$2.54^{+0.07}_{-0.21}$
$NRQCDNLO + RC$[20]	$3.85^{+0.04+0.54}_{-0.02-0}$

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10 July 2017, Poster Session, EPS-HEP conference, Venice, Italy, 5-12 July.